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Assessment of the First Use of the Uniform Sky Strategy in Scheduling the Operational IVS-INT01 Sessions

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Abstract

The primary purpose of the IVS-INT01 sessions is the estimation of UT1. Improving the accuracy and the precision of the UT1 estimates is an important goal in the scheduling of these sessions. In 2009 and 2010, the GSFC VLBI Analysis Center requested and received the use of nine IVS R&D sessions for the evaluation of a new strategy for scheduling the IVS-INT01 sessions. This strategy maximizes sky coverage and the number of scheduled sources, and it has now been named the Uniform Sky Strategy. The initial results were sufficiently promising that in July 2010, the USNO NEOS Operation Center began to alternate the use of the original and new strategies in scheduling the operational IVS-INT01 sessions in order to develop a basis for assessing the operational effectiveness of the new strategy. After a three-month hiatus during which one of the IVS-INT01 stations was unavailable due to repairs, the alternating series resumed in early December 2010, and it has now generated over a year of continuous data. This paper assesses the operational effectiveness of the Uniform Sky Strategy.

1. Introduction

The primary purpose of the IVS-INT01 sessions is estimating UT1. Therefore improving the accuracy and the precision of the UT1 estimates is an important goal in scheduling these sessions. Better sky coverage has been empirically linked to better UT1 estimate precision. But the original, standard scheduling strategy (STN) uses only the strongest sources, and because strong sources are unevenly distributed, there are only a few strong sources available at some times of the year, resulting in bad sky coverage. The worst source availability occurs in early October (Figure 1), but other times of the year could also use improvement.

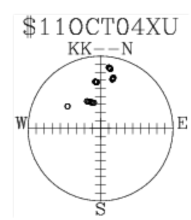


Figure 1. AZ-EL sky coverage using the STN at the Kokee station in early October, when the STN typically has the worst sky coverage and the worst UT1 formal errors.

To address this, in 2009 the GSFC VLBI Analysis Center proposed a new scheduling strategy, the USS (Uniform Sky Strategy), which uses all geodetic sources that are mutually visible at the regular IVS-INT01 stations (Kokee and Wettzell) with the goal of improving sky coverage. The USS introduces new, but weaker, sources. The result is a lowering of the average source strength and a lowering of the session observation counts because it takes longer to observe a weaker source. This has the effect of degrading UT1 formal errors. So the new strategy works both in favor of and against the UT1 formal errors, creating a need to carefully test the strategy.

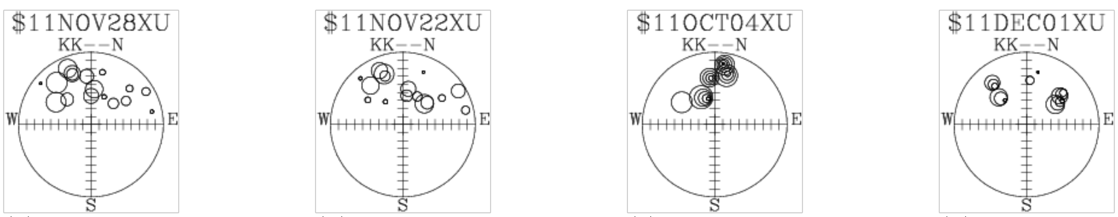
From July 2009 through June 2010, the GSFC VLBI Analysis Center used nine IVS R&D sessions to evaluate the USS. Based on this evaluation, in July 2010 the USNO NEOS Operation

Center began to alternate the use of the STN and USS strategies in scheduling the operational IVS-INT01 sessions, in order to develop a basis for evaluating the operational effectiveness of the USS strategy. After a three-month hiatus during which Wettzell was unavailable due to repairs, the alternating series resumed in December 2010. This paper evaluates the USS by comparing the alternating USS and STN sessions that were observed during 2011.

2. Spatial vs. Temporal Coverage

Two types of sky coverage apply to sessions — spatial (how much of the sky is sampled at least once during the session) and temporal (how frequently areas of the sky are sampled). A session might have good spatial coverage, if most areas of the sky are sampled at some point during the session, but it might have bad temporal coverage if many of the areas are only sampled once—especially at the session's beginning or end. A session with good spatial coverage can have good or bad temporal coverage, depending on the order of its observations. But bad spatial coverage guarantees bad temporal coverage; an area cannot have any temporal coverage unless it has spatial coverage. So temporal coverage depends on and is subordinate to spatial coverage.

The USS and the STN strategies differ in their provision of spatial and temporal coverage. Figures 2a through 2d show spatial and temporal coverage in four representative USS and STN sessions. The circles show observation positions on an AZ-EL sky coverage plot at Kokee, and the sequence of observations is shown by circles of increasing size.



(a) (b) (c) (d)

Figure 2. a) USS: good spatial coverage, but uneven, bad temporal coverage; the later observations (largest circles) are clustered in one part of the sky, b) USS: good spatial and better, more even temporal coverage, c) STN: bad spatial and bad temporal coverage (but even temporal coverage within the source set), and d) STN: good spatial coverage with good (and even) temporal coverage.

The USS gives good spatial coverage throughout the year (Figures 2a and 2b), but temporal coverage varies in this strategy. The USS observes many sources, usually only once; depending on the order, the USS may restrict its sampling to one area of the sky, then abandon it to sample another area, providing uneven, bad coverage over time (Figure 2a). Better, more even temporal coverage can also occur (Figure 2b), but only by chance.

Evenness of temporal coverage is much less of an issue with the STN strategy; it uses fewer sources, so the sessions tend to observe sources repeatedly (subject to observation loss and the rising and setting of sources). The primary issue with the STN strategy is the degree of spatial coverage, which varies throughout the year and directly affects the level of temporal coverage that can be achieved. The strategy provides good or bad temporal coverage depending on the available sources (Figures 2c and 2d).

3. Analysis of Data from the Alternating USS and STN Sessions from Observing Year 2011

3.1. Accuracy of the USS

Figure 3 compares the USS and STN UT1-TAI totals estimated by the Solve software package to totals from the IERS 08 C04 series by showing the difference between each session's UT1-TAI total and a value obtained by interpolating the C04 series to the total's epoch. The RMS of the differences is $\sim 2\ \mu s$ smaller in the USS case, indicating that the USS is a better match to C04. In addition, USNO's Earth Orientation Parameters Division has verified that the USS values are acceptable through its operational combination solutions.

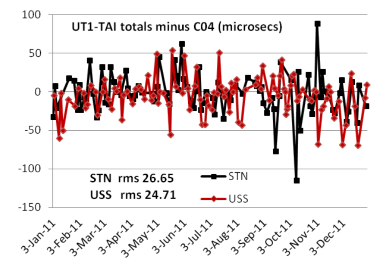


Figure 3. UT1-TAI totals minus C04 for the observing year 2011.

3.2. Effect of the USS on the UT1 Formal Errors

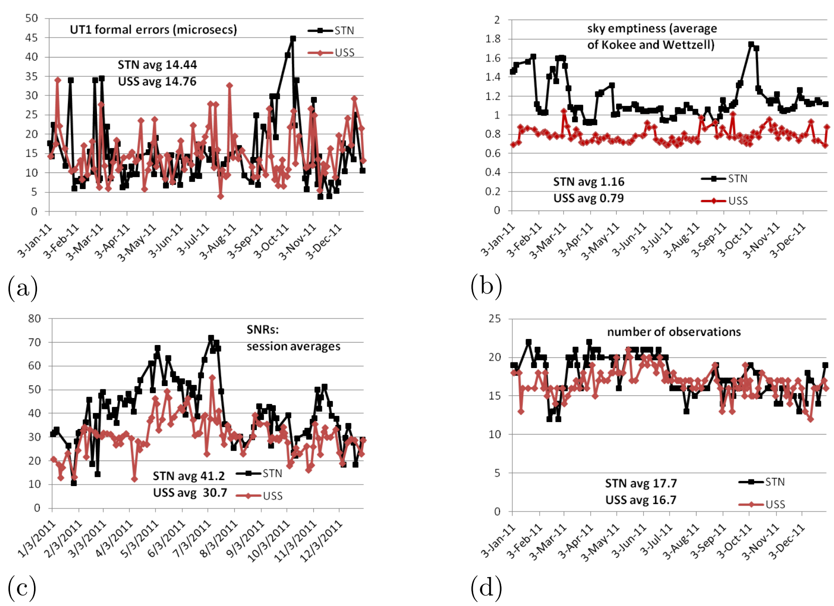


Figure 4. Sessions during the observing year 2011: a) UT1 formal errors, b) sky coverage (measured by sky emptiness), c) average SNRs, and d) session observation counts. Sky emptiness at each station was determined by evenly sampling the sky at one-degree intervals, calculating the angular distance between each sampled point and its nearest observation, adding the angular distances, and scaling the sum by 100,000. Each session was then assigned the average of its Kokee and Wettzell values. Additional calculations took into account a 5° elevation horizon mask and the method's redundant sampling at higher declinations.

As mentioned before, better UT1 formal errors are a goal in scheduling the IVS-INT01 sessions, but the USS strategy offers trade-offs that work for and against the UT1 formal errors. Figure 4a shows the UT1 formal errors estimated by Solve for the observing year 2011 USS and STN sessions. The USS meets one goal by greatly reducing the UT1 formal errors during early October, but its UT1 formal errors exceed those of the STN at some other times of the year. Overall, the USS has slightly worse average formal errors than the STN (14.76 vs. 14.44 μs).

Sky coverage, source strength, and session observation counts affect the UT1 formal errors. Figure 4b indirectly shows sky coverage by showing sky emptiness, which can be measured by sampling the sky and summing the angular distances between each sampled point and the nearest observation. A smaller sum indicates less emptiness, or more coverage. As expected, the USS has better sky coverage, which should lower the UT1 formal errors. But it has generally worse average SNRs and session observation counts (Figures 4c and 4d) which should raise them. On the surface, this suggests that the USS method of including as many sources as possible is including weak sources that may outweigh the benefits of achieving better sky coverage, so that using an intermediate set of sources between those of the STN and the USS strategies — a set that adds fewer sources in order to only add sources of intermediate strength — might be a better approach. But other factors currently under investigation might be affecting the UT1 formal errors as well.

4. Robustness Simulations

4.1. Simulation 1: Effect of Noise on the UT1 Estimates

A session is robust if its UT1 estimate does not change much with random noise, such as atmospheric fluctuations. In simulation 1, we ran the Solve solution configuration used for Section 3, but we added random noise that simulates atmospheric turbulence, and we ran the modified solution 100 times per session. We then calculated the RMS of each session's UT1 estimates about the mean (Figure 5). Schedules that are less vulnerable to noise have a lower RMS.

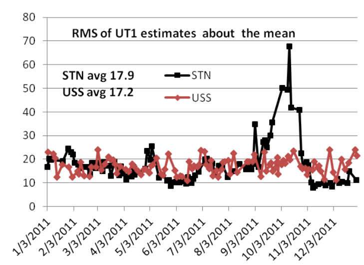


Figure 5. Effect of noise on the USS and the STN UT1 estimates (μs).

The average of the USS sessions' RMS values is lower than the STN average (17.2 vs. 17.9 μs), and the USS has much lower values in early October. But the STN values are better at other times, and the STN sessions achieve a lower minimum RMS (8.02 vs. 11.04 μs).

The USS RMS values range from 11.04 to 24.06 μs, and many STN values (∼67%) are comparable. But ∼19% are better (8.02 to 10.58 μs), and ∼14% are worse (24.64 to 67.64 μs). Examination of the RMS values and the year 2011 temporal AZ-EL plots shows a relationship between spatio-temporal coverage and the RMS values. The USS sessions tend to have good, fairly consistent spatial coverage with varying temporal coverage. The USS RMS values have a correspondingly small range of variations, and the variations loosely correspond to variations in the temporal coverage, although reduced spatial coverage due to lost observations is also a factor. More study is needed, but probably sessions with better temporal coverage (Figure 2b, RMS = 11.36 μs), are more likely to catch atmospheric fluctuations over time, allowing the fluctuations to "average out" more than in sessions with worse temporal coverage (Figure 2a, RMS = 23.97 μs). The STN spatial coverage and RMS values vary greatly, with better values generally linked to better spatial coverage. STN temporal coverage tends to improve with spatial coverage. So sessions with better spatial coverage probably are better at sampling spatially and temporally uneven atmospheres, again allowing the atmospheric sampling to average out. Only the two northern AZ-EL quadrants are mutually visible at Kokee and Wettzell. The STN sessions with the lowest

RMS values sample the atmosphere at two positions, each of which is roughly near the center of one of Kokee's northern quadrants (Figure 2d, RMS = 8.36 μs). Wettzell's positions are similar, although shifted towards the horizon. The STN sessions with the highest RMS values only sample one position, the center of the combined quadrants (Figure 2c, RMS = 50.24 μs), or they only sample one quadrant. So the best STN sessions provide approximately double the spatial coverage of the worst STN sessions.

It is counterintuitive that the best USS sessions have better sky coverage but have larger RMS values than the best STN sessions. More study is needed, but the USS sessions include lower elevation observations, which probably introduce more noise and raise the RMS, apparently more than the better sky coverage lowers it. Low elevation observations also seem to contribute to STN RMS variations. The worst STN session (RMS = 67.64 μs) covers more sky than the second worst STN session (RMS = 50.24 μs), but it has more low elevation observations.

Although the STN RMS values are lower than the USS values at times, the STN values are very high during early October. Because of this, and because the USS has a lower average RMS, the USS is the better strategy for protection against random noise. But it must provide good temporal coverage and possibly restrict its use of low elevation observations to maximize this protection.

4.2. Simulation 2: Effect of Source Loss on the UT1 Estimates

A session is robust if its UT1 estimate does not change much when it fails to observe one of its scheduled sources.

In simulation 2, we tested the effect of losing a single source on the UT1 estimates. Using the Solve solution configuration used for Section 3, we ran a set of solutions for each session in which we suppressed the session's sources, one at a time. We then calculated the RMS of each session's UT1 estimates about the mean (Figure 6). Schedules that are less vulnerable to the loss of a source have a lower RMS. Figure 6 shows that throughout the year, the USS RMS values are almost always lower than or equal to the STN values. In addition the average of the USS RMS values is ~2.5 times as good as the STN average. The USS provides much better protection against source loss than the STN, because the USS schedules use more sources and their sky coverage is better. The loss of a single source does not change the sky coverage as much as in the STN schedules.

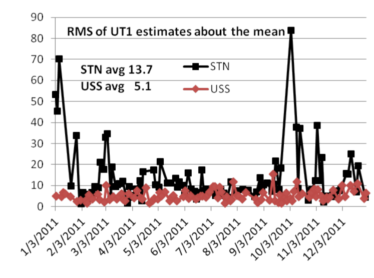


Figure 6. Effect of source loss on the USS and the STN UT1 estimates (μs).

5. Conclusions

The USS improves the early October UT1 formal errors, and it provides better overall protection against source loss and noise than the STN does. But the USS UT1 formal errors are higher than the STN UT1 formal errors at some times of the year, and the average of the USS formal errors is slightly higher. The USS also provides worse protection against noise at times. So factors that affect the formal errors (e.g., the balancing of sky coverage and source strength) and factors that seem to affect noise protection (e.g., temporal coverage and low elevation observations) should be investigated further. We conclude that the USS is a good first step towards improving the IVS-INT01 schedules, and it should be retained but also further refined.